Introduction to **Comets**

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Antiquity to the fifteenth century

Prehistoric man must have had a sophisticated knowledge of the night sky, judging from the recent discoveries by archeoastronomers. There can be little doubt that early man came to know the sky – its diurnal risings and settings, its seasonally shifting patterns of stars, its changing lunar phases – as both a clock and a calendar. One can try to imagine the reaction of a prehistoric people to the mysterious appearance of a bright comet in the sky. Probably other notable events would have occurred at the same time – the death of a loved one, the birth of a child, a killing drought, or an especially successful hunt. If they were at all superstitious, early people would have viewed the comet as an omen for whatever important event occurred while it was visible.

When we study the history of man's views of nature, we find that comets have always been surrounded by an aura of awe and mystery. Many people shared Aristotle's view that the appearance of a comet signaled disaster or drought. The appearance of a bright comet struck fear in the hearts of its viewers, and with the fear came considerable interest. Even today, the appearance (or potential appearance) of a bright comet sparks immense public interest; the story of Comet Kohoutek is a case in point.

Over two thousand years ago, the Roman sage Seneca speculated: "Some day there will arise a man who will demonstrate in what regions of the heavens comets take their way; why they journey so far apart from the other planets; what their size, their nature" (Hellman, 1944:33). So far this man has not arisen, and there is little chance that he will arise in the near future. Today, we still do not know the answers to these perplexing questions. Many professional comet workers (the authors included) regard these mysteries as one of the great charms of comets.

Many concepts of the nature of comets were extant during Greek and Roman times. The Greeks gave us the word *comet* (κομήτης), which means "long-haired one." The Latin word for hair (*coma*) has survived as a part of cometary terminology. When one sees a bright comet with its long, wispy tail, it is not difficult to see the origin of the concept of a comet as hairy.

A study of the views about comets held by ancient thinkers is hampered by one serious drawback: We do not often have access to the original writings but must rely on secondhand sources such as Aristotle and Seneca. Even so, we do have some very old records of comets. Among the oldest is a Babylonian inscription interpreted as a reference to the comet of 1140 B.C. "A comet arose whose body was bright like the day, while from its luminous body a tail extended, like the sting of a scorpion."

The history of cometary thought began entirely as a debate over whether comets were celestial objects or phenomena of the atmosphere. The debate started early. The Babylonians (or Chaldeans) are credited with the ideas that comets were cosmic bodies, like planets, with orbits, and that comets were fires produced by violently rotating air. The Pythagoreans (sixth century B.C.) and Hippocrates (c. 440 B.C.) are reported to have considered comets as planets that appeared infrequently and, like Mercury, did not rise very far above the horizon. Hippocrates and his student Aeschylus also believed that the tail was not an integral part of the comet but rather an illusion caused by reflection. Anaxagoras (499–428 B.C.) and Democritus (c. 420 B.C.) thought that comets were conjunctions of planets or wandering stars; Democritus apparently believed that certain stars were left behind when comets dissolved. Ephorus of Cyme (405–330 B.C.) reported that the comet of 371 B.C. split into two stars. Seneca considered this an impossibility and accused Ephorus of spicing up his tales for public consumption. We know today that the splitting of a comet is quite possible (e.g., Biela's comet, Chapter 4). It is not difficult to see how such an observation could lead to the view that comets were formed by a coalescence of stars.

A contemporary of Aristotle, Apollonius of Myndus, rejected the view that comets were an illusion or fire and asserted that they were distinctively heavenly bodies with orbits. Some of the early concepts of comets seem quite reasonable to us today. Certainly, many thinkers viewed comets as celestial objects. However, the influential ideas of almost two millennia were those of Aristotle (384–322 B.C.), as set forth in his *Meteorology* (1952). In this famous work, he first discussed the views of others, then presented his own concepts. Aristotle ruled out the planetary nature of comets by asserting that they had been seen outside the zodiac. In addition, comets could not be caused by a conjunction of planets or a coalescence of stars because many comets had been observed to fade away without leaving behind one or more stars.

Aristotle apparently was impressed with the irregular and unpredictable nature of comets, particularly when contrasted to his philosophical concept of the unchanging nature of the heavens. Hence, he considered that they could not be astronomical bodies but were the product of meteorological processes in our atmosphere; specifically, they lay below the moon. He wrote:

We know that the dry and warm exhalation is the outermost part of the terrestrial world which falls below the circular motion. It, and a great part of the air that is continuous with it below, is carried around the earth by the motion of the circular revolution [the same motion that carries the celestial sphere around the earth]. In the course of this motion it often ignites wherever it may happen to be of the right consistence . . . We may say, then, that a comet is formed when the upper motion introduces into a gathering of this kind a fiery principle not of such excessive strength as to burn up much of the material quickly, nor so weak as soon to be extinguished, but stronger and capable of burning up much material, and when exhalation of the right consistency rises from below and meets it. The kind of comet varies according to the shape which the exhalation happens to take. If it is diffused equally on every side the star is said to be fringed, if it stretches out in one direction it is called bearded. [Aristotle, 1952:450.]

This embryonic classification scheme for comets actually survived at least until books written on the comet of A.D. 1577. Aristotle apparently accepted the idea that comets were omens of droughts and high winds. On Aristotle's own ground, this follows somewhat logically because of the ''fiery constitution'' of the exhalation. Finally, Aristotle thought that the Milky Way was composed of the same material as the comets.

It is easy to be impatient with and critical of Aristotle's views, but this is not fair. His hypothesis, considered in light of the physics of the era, was a good attempt to explain the sudden appearance, unusual movements, and highly irregular shapes of comets. Aristotle himself considered his explanation satisfactory if it was free of impossibilities. Our ire should be reserved for those investigators 2000 years later who could do no better.

Aristotle's ideas gradually grew in importance. Posidonius (135–51 B.C.) synthesized Aristotle's and added some of his own. Although he regarded comets as atmospheric phenomena, he stated that there were more comets than are usually observed because some are lost in the glare when near the sun. This idea came from an observation made by Posidonius himself of a comet near the sun becoming visible during a total solar eclipse. The classification of comets was according to their shapes. Views similar to Posidonius' were given by Arrian (second century A.D.) in a monograph on comets.

Seneca (4 B.C.–A.D. 65) had a classification scheme similar to those previously mentioned. Although he also reviewed previous knowledge, his writings on comets (found in his *Questiones naturales*) are very different. To us, they seem like those of a scientist assaying a situation, and they are filled with apparent flashes of insight. For example: "I cannot think a comet is a sudden fire, but I rank it among Nature's permanent creations" (Hellman, 1944:31). We also find:

> If it were a wandering star [i.e., a planet], says some one, it would be in the zodiac. Who say I, ever thinks of placing a single bound to the stars? or of cooping up the divine into narrow space? These very stars, which you suppose to be the only ones that move, have, as every one knows, orbits different one from another. Why, then, should there not be some stars that have a separate distinctive orbit far removed from them? [Hellman, 1944:32]

Elsewhere we read:

> There are many things whose existence we allow, but whose character we are still in ignorance of . . . why should we be surprised, then, that comets, so rare a sight in the universe, are not embraced under definite laws, or that their return is at long intervals? . . . The day will yet come when the progress of research through long ages will reveal to sight the mysteries of nature that are now concealed . . . The day will yet come when posterity will be amazed that we remained ignorant of things that will to them seem so plain. [Hellman, 1944:33]

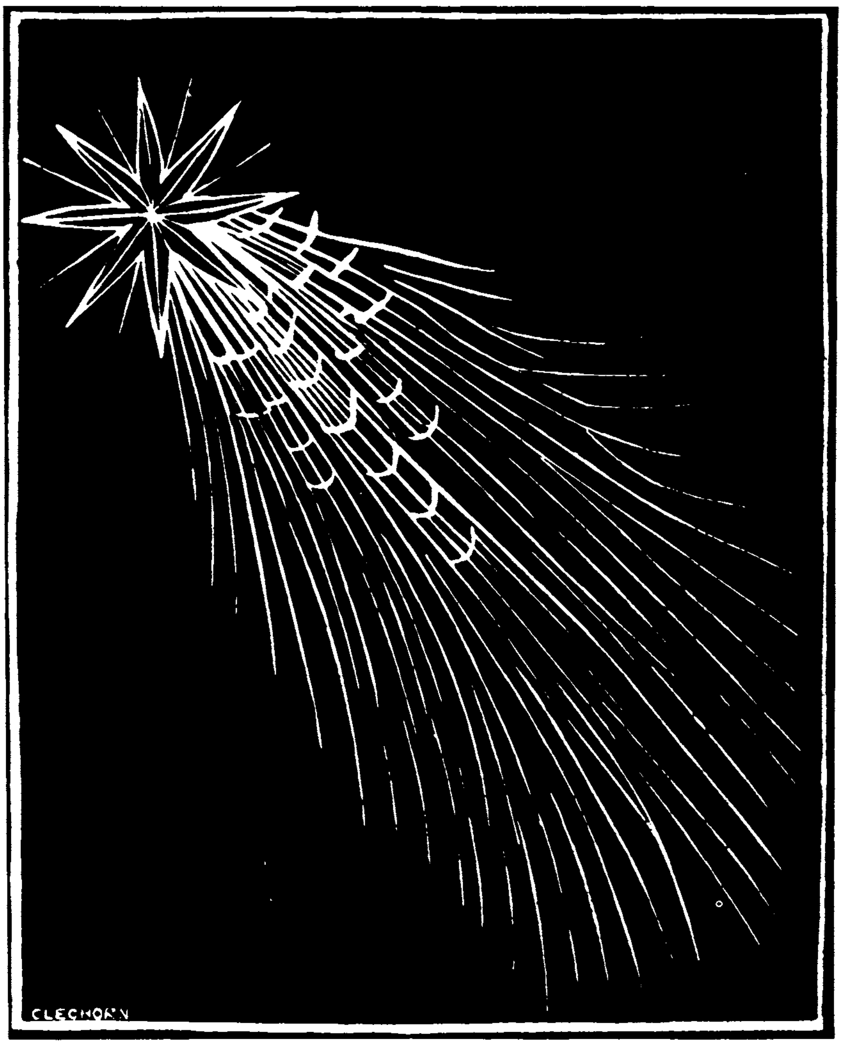
Even Seneca was somewhat under the influence of his illustrious predecessor. He classified comets under meteorology, and he discussed weather forecasting from the appearance of comets.

Pliny the Elder discussed comets in his *Natural History*, which appeared about A.D. 77; Seneca is not mentioned as a source. Pliny presented a classification scheme based on appearance (both shape and color) that was used for centuries. However, his discussion of comets included little that was new, and many of his statements were not very specific.

It is curious that comets were not mentioned in Ptolemy's (second century A.D.) *Almagest* and were barely mentioned in his other works, and then only in connection with weather prediction. Ptolemy did argue that events on earth were not inevitably influenced by the stars. Arguments of this nature encouraged the notion (which persisted at least into the sixteenth century) that prayers would help avert the undesirable influences of comets.

Cometary studies did not flourish in the centuries following Ptolemy, and Hellman (1944:9) has noted that the years up to the fifteenth century "were not productive of any new cometary theory." Of course, this does not mean that comets were not observed and recorded; appearances of bright comets such as Halley's were recorded, for example, in A.D. 684 in the *Nuremberg Chronicles* and in 1066 in the Bayeux Tapestry (see Figures 1.1 and 1.2). Men such as Bede (A.D. 673–735), Thomas Aquinas (c. 1225–74), and Roger Bacon (c. 1214–94) wrote about comets. Despite variations in individual writings, the astrological view of comets was strengthened, particularly the belief that comets were evil omens. The scientific data recorded in Europe and the Middle East were often just sufficient to identify appearances of the periodic comets. Cometary observations by the Chinese have not been mentioned here because they had little or no influence for centuries on the main development of cometary knowledge.

Figure 1.1. The A.D. 684 apparition of Halley's comet as recorded in the *Nuremberg Chronicles*. (Yerkes Observatory photograph)



Beginning of the fifteenth century to the supernova of 1572

European civilization was slowly climbing out of the medieval period as the fifteenth century opened with the appearance of two bright comets in 1402. Slow progress toward our modern view of comets also began. Some individuals began to study comets in a systematic manner – gathering facts, probing their nature – rather than exploiting them with the superstitious people. How slowly this change came about can be judged, as noted by Hellman (1944:16), by the fact that Pingré in his famous *Cométographie,* published in the 1780s, "still considered it necessary to refute Aristotle." Aristotelian theory was extended in the 1450s by Matthew of Aquila, who associated comets and earthquakes. He also considered that comets not only signaled evil but could cause evil because, in Hellman's words, "their hot, putrid vapors contaminated the air" (Hellman, 1944:73).

Paolo Toscanelli[1] (1397–1482) observed Halley's comet at its 1456 appearance, as well as several other comets. His positional observations for a number of comets that he observed between 1433 and 1472 were sufficiently accurate to permit the calculation of orbits by later

Figure 1.2. The 1066 apparition of Halley's comet as recorded on the Bayeux Tapestry.

workers. Peurbach (1423–61) also observed the comet of 1456 and by attempting to measure its distance may have been the first to do so.

A spate of activity was associated with the great comet of 1472. The principal contribution was made by the legendary but controversial Johannes Müller (1436–76), who is usually known by his adopted Latin name, Regiomontanus. His work on the comet was divided into sections whose titles were a list of problems to be investigated. These include the diameter of the comet, the position of the comet, the length and thickness of the tail, and the distance to the comet by measuring its parallax. His observations were not sufficiently accurate to permit him to infer a meaningful parallax, and his value of 6° is highly erroneous. Nevertheless, either he or Peurbach was the first to attempt such a measurement. In evaluating Regiomontanus' contribution, we must also bear in mind what he did not do. His writings contain no discussions of the "meaning" of the comet, nor did he issue astrological predictions based on the appearance of the comet.

The concept that comet tails point away from the sun was well known by the mid-sixteenth century. The Italian astronomer Fracastoro (c. 1480–1553) wrote *Homocentrica* in 1538 in an attempt to improve upon the Ptolemaic theory of planetary motions by reverting back to concepts of the early Greek thinkers. The effort was not destined to bear fruit, because Copernicus' great *De revolutionibus* was already written and would be published 6 years later. However, Fracastoro did describe his observations of several comets, and he noted that the tails always pointed away from the sun. Fracastoro was not alone in this important observation. Peter Apian described observations of several comets that appeared in the 1530s in his *Astronomicum Caesareum* (1540) and remarked that the cometary tails pointed away from the sun. In his *Practica* (1532), Apian described the appearance of Halley's comet at its 1531 apparition, and a woodcut on the title page shows the tail axis extending through the sun. The figure facing p. 1 of the present text shows Apian's remarkable observations of Halley's comet in 1531.

The close proximity in time of the writings of Fracastoro and Apian has led to some debate over who deserves credit for the discovery. In fact, the exact origin of our understanding of the orientation of comet tails is probably lost in antiquity. Chinese astronomers, in describing their observations of a comet in A.D. 837, said as much, and Seneca in his *Questiones naturales* wrote that "the tails of comets fly from the sun's rays" (Seneca, 1910).

In 1550, Jerome Cardan published his *De Subtilitate,* which was a compendium of learning. Cardan's views on cometary science were of considerable interest. He was aware of the parallax method for determining the distance to comets. His views on the origin of comets as summarized by Hellman (1944:93) read: "A comet is a globe formed in the sky and illuminated by the sun, the rays of which, shining through the comet, give the appearance of a beard or tail." Cardan also thought that there were more comets than the ones observed.

The comet of 1533 was observed by Copernicus; unfortunately, the observations have been lost. We may safely conclude that he made no significant contribution to cometary knowledge.

A sure sign of at least some maturity of an astronomical subject appeared at the time of the comet of 1556, when some of the earliest catalogues of comets were published. At least three such catalogues were issued within a span of only a few years.

The last key event before the studies of the comet of 1577 was the supernova of 1572, which was visible for a year in the constellation Cassiopeia. Hellman (1944:111) explicitly states that "the influence of the new star of 1572 in moulding the astronomical thought of the period cannot be overestimated." The principal observer of the supernova was Tycho Brahe (1546–1601), generally considered to be the greatest astronomer of his day. Tycho made and recorded positional observations with the high accuracy for which he is renowned. He failed to detect any parallax, and he placed the new star in the region of the fixed stars. In retrospect, it is curious that Tycho concluded that the new star could not be a comet or meteor because these were formed below the moon.

Tycho's observations were rivaled only by the work of Thomas Digges (c. 1564–95) in England. Observations were also made by Michael Maestlin and by Hagecius in Bohemia. The conclusion reached by all the authors mentioned was that the new star had no measurable parallax and belonged to the region of the fixed stars. Although there were some dissenting voices concerning the parallax, the basic result was established, as well as an eager and receptive climate for the appearance of the comet of 1577.

The comet of 1577

Tycho Brahe observed this famous comet from November 13, 1577, to January 26, 1578. His observations and views were contained in a Latin work, *De Mundi Aetherei Recentioribus Phaenomenis,* and a German work. Tycho summarized earlier work on comets and ideas concerning the structure of the universe. Aristotle's views on the immutability of the heavens were questioned on the basis of the new star of 1572. Tycho also questioned the atmospheric origin of comets because, if that concept were true, he could see no reason for their tails always to point away from the sun. Nevertheless, Tycho felt that the conclusive method for discovering the comet's true place was to measure its parallax.

Tycho measured the position of the comet among the stars when the comet was high and low in the sky and compared the results. If the comet was between the earth and the moon, a parallax of at least 1° should have been found. The average error of Tycho's positions (established by comparison with a modern orbit for the comet) was only 4′; we also know that he was well aware of the effects of refraction. Tycho was cautious and concluded that the comet's parallax was 15′ or less, placing it at least 230 earth radii away. This distance is well beyond the moon, which averages 60 earth radii away. Comparison of Tycho's observations from the island of Hveen (near Copenhagen) with observations made by Hagecius at Prague showed a difference in position of only one or two minutes of arc. If the parallax was 2′, and noting that Prague and Copenhagen are about 600 km apart, the comet would be at a distance of approximately 1 million km, well beyond the moon's mean distance of about 380,000 km.

Thus, Tycho concluded that the comet lay between the moon and Venus. He even attempted to calculate an orbit[2] for the comet. His result was a circular orbit around the sun outside of the orbit of Venus. Of course, he could not represent the observed motion of the comet, assuming it traveled in a circular orbit with uniform motion. He was obliged, therefore, either to assume an irregular motion or to admit that the orbit was not "exactly circular but somewhat oblong, like the figure commonly called oval" (Dreyer, 1953:366). Sarton interprets Tycho as having suggested that the comet's orbit was elliptical. Whether an ellipse or just an oval was meant, Dreyer (1953:366) notes: "This is certainly the first time that an astronomer suggested that a celestial body might move in an orbit differing from a circle, without distinctly saying that the curve was the resultant of several circular motions." Tycho's work *De Mundi Aetherei Recentioribus Phaenomenis* was first published in 1588, and Kepler's result that planteary orbits were ellipses was contained in his book on Mars, which appeared in 1609. The question of the shape of cometary orbits will become more curious when we look at Kepler's own views below.

Tycho attempted to calculate the linear dimensions of the comet, which, of course, depended on the distance assumed. The measured angular dimensions on November 13 were a head diameter of 8′, a tail length of 22°, and a tail breadth of 2.5°. Tycho realized that the linear dimensions of the comet were tremendous even if the comet looked small to terrestrial observers.

Tycho expressed his opinion that the tail is caused by sunshine passing through the comet: Because comets are not diaphanous, sunlight cannot pass through without effect and because comets are not thick and opaque like the moon, sunlight is not simply reflected. A comet is intermediate and partly holds the sunshine. Because a comet's body is porous, some sunbeams are allowed to pass through and are seen by us as a tail attached to the head.

Thus, comets were not atmospheric and were not sublunar. They were supralunar celestial objects that could be studied by scientific methods. The lack of appreciable parallax clinched these conclusions. There was really no need to take the Aristotelian view seriously thereafter. Tycho's work was confirmed by astronomer Michael Maestlin (1550–1631) and by others.

Of course, there were dissenters from Tycho's conclusions about the comet of 1577. Of first importance was Tadeáš Hájek Hájku, known by his latinized name of Hagecius (c. 1526–1600); he was considered a leading astronomer of his time. He initially obtained a parallax of 5°, which would have placed the comet well below the moon and, in fact, only about 8 radii from the earth's center. Hagecius' observations were good, and Tycho used them to establish independently the supralunar position of the comet. Hagecius had erred in his interpretation of his imprecise observations. He established himself as a man of considerable scientific character by admitting that he was wrong. He recognized the comet as supralunar in his work on the comet of 1580.

Other observers found a large parallax for the comet, but the quality of this contemporary work was not close to Tycho's. The most serious attacks on Tycho would occur after his death.

Beginning of the seventeenth century to the comets of 1680 and 1682

Johannes Kepler (1571–1630) worked on the comets of 1607 (Halley's) and 1618, and published his views on comets in *De Cometis* (1619) and in *Hyperaspistes* (1625). His ideas on the formation of comet tails and the ultimate extinction of comets seem remarkably modern. He wrote:

> Gross matter collects under a spherical form; it receives and reflects the light of the sun and is set in motion like a star. The direct rays of the sun strike upon it, penetrate its substance, draw away with them a portion of this matter, and issue thence to form the track of light we call the tail of the comet. This action of the solar rays attenuates the particles which compose the body of the comet. It drives them away; it dissipates them. In this manner the comet is consumed by breathing out, so to speak, its own tail. [Olivier, 1930:9]

Today we believe that comets shine by reflected light and that their tails are formed by solar radiation pressure. Kepler also considered that comets were as numerous as fish in the sea.

Kepler's beliefs concerning the orbits of comets are curious indeed. He thought that comets moved along straight lines, but with an irregular speed. Because Tycho had suggested an oval or elliptical orbit for comets, and because Kepler himself found elliptical orbits for the planets, this oversight is all the more puzzling.

Kepler would once again become involved in comet work because of attacks on Tycho by Scipio Claramontius (1565–1652) (sometimes called Chiaramonti) and by Galileo. In Claramontius work, *Antitycho* (1621), he attempted to prove that comets were sublunar. Among other things, Claramontius may not have been straightforward because, as Drake and O'Malley (1960:374) have noted: "One of the favorite devices of Chiaramonti was to attack the data of astronomers as inaccurate because they were never in exact agreement. On this pretext, he would throw out all the observations which did not suit his purpose." Claramontius convinced only a few, and his writings did not greatly hinder acceptance of the new approach to comets.

The criticisms of Galileo Galilei (1564–1642) were more serious. Three comets appeared in the year 1618 and an exchange of differing opinions began; the exchange produced Galileo's work dealing with comets, *The Assayer* (1623). Galileo was not in good health, and he did not personally observe the comets extensively. Perhaps he used comets to publicize his scientific methods. In any case, Galileo's antagonism toward Tycho shows clearly in *The Assayer.* Galileo dismissed the parallax observations by noting that the comet could be simply an optical illusion. He suggested that vapors rising from the earth's atmosphere could produce comets seen by reflected sunlight when the vapors had risen outside the cone of the earth's shadow. A clever argument by Father Horatio Grassi (1583–1654) was that comets were quite distant because they were not magnified by telescopes; Galileo argued that this was not necessarily so if strange optical effects were involved. The curvature of some comet tails caused great difficulties to all concerned.

All in all, the writings concerning the comets of 1618 are not enlightening. For example, luminous gas was supposed to be both opaque and transparent by the opposing sides. It is painful to read that the biblical description of Shadrack, Meshack, and Abednego walking uninjured in the midst of fire after they had been cast into the furnace was used as evidence by both sides.

Kepler responded to the unjust criticisms of Tycho by Claramontius in his book *Tychonis Brahei Dani Hyperaspistes* or *The Shieldbearer to Tycho Brahe the Dane* (1625). He disposed of Claramontius' views on

Figure 1.3. Three allegorical figures showing the Aristotelian idea that comets are sublunar (left), the Keplerian notion that comets move in a straight line (right), and the idea of Hevelius (center) that comets originate in the atmospheres of Jupiter or Saturn and move about the sun on a curved trajectory. (Frontispiece from Hevelius's *Cometographia,* published 1668 in Danzig.)

the parallax by noting the well-established accuracy of Tycho's observations. Kepler responded to Galileo in an appendix to the *Hyperaspistes*. This reply contains some of Kepler's ideas on comets, mentioned above.

Newton, Halley, and the orbits of comets

The problem of cometary orbits began to be resolved in 1665 when Giovanni Borelli (1608–79), using a pseudonym, published the suggestion that the paths of comets were parabolic. The same suggestion was made by Johannes Hevelius[3] (1611–87), who discovered four comets and wrote two books on comets (Figure 1.3). His ideas on the motion of comets involved an origin in the atmospheres of Jupiter or Saturn and a resisting medium in interplanetary space. A comet began its orbit toward the sun with the flat part of its "disk" oriented perpendicularly to the direction of motion. But when the comet approached the sun, it moved with the edge of the disk forward. The reduced effect of the resisting medium caused a departure from the initial rectilinear path; the resulting path could be either a parabola or a hyperbola, although Hevelius did not put the sun at the focus. The comet of 1680 was studied by a student of Hevelius, George Dörffel, who suggested that its orbit could be represented by a parabola with the sun at the focus.

Isaac Newton (1642–1727) wrote the great book *Philosophiae Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*) or *Principia*, which was published in several editions, the first in 1687, the second in 1713, and the third in 1726. The *Principia* was translated from Latin into English by Andrew Motte in 1729. This English rendition of the third edition was revised and supplied with a historical and explanatory appendix by Florian Cajori and published together with Newton's *System of the World* in 1934. Comets are an important part of both these books. Edmond Halley, who was instrumental in seeing that the *Principia* was published, played an important role in Newton's interest in comets. Halley's contribution was diplomatic and financial as well as scientific, moving A. De Morgan (1806–71) to write: "but for him, in all human probability, that work would not have been thought of, nor when thought of written, nor when written printed."

Newton's laws of motion and gravitation established the basis for calculating cometary (as well as planetary) motion. Newton gave a method for computing parabolic orbits for comets from three observations. He knew that most comet orbits near the sun could be represented very accurately by parabolas. In 1695, Halley began to calcu-

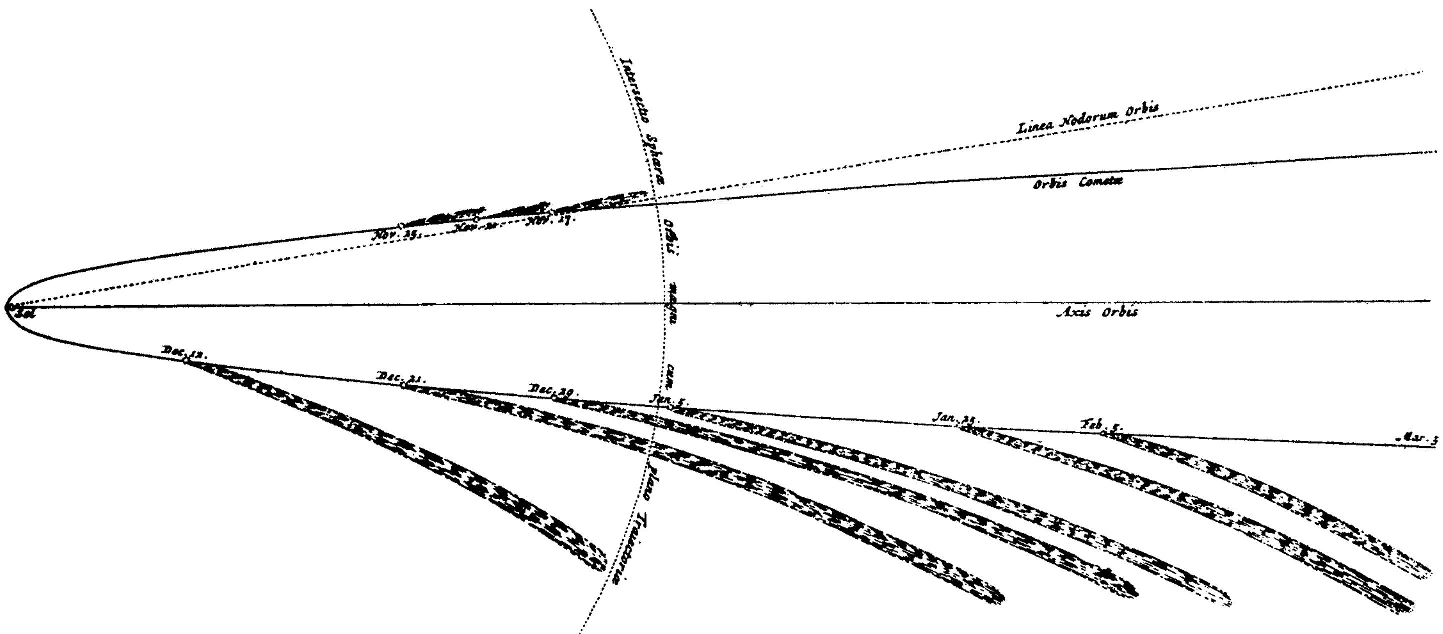


Figure 1.4. Halley's orbit for the comet of 1680 as given in Newton's *Principia*.

late the orbits of several well-observed comets. The orbit for the comet of 1680 was discussed extensively in the *Principia,* and a diagram representing the comet's orbit and tail orientation was presented (Figure 1.4).

In referring to this orbit and the agreement with observation, Newton wrote in the *Principia:* "The orbit is determined . . . by the computation of Dr. Halley, in an ellipse. And it is shown that . . . the comet took its course through the nine signs of the heavens, with as much accuracy as the planets move in the elliptic orbits given in astronomy" (Newton, 1686:Book III). Thus, Newton concluded that "comets are a sort of planet revolved in very eccentric orbits around the sun."

Newton's views on the physical constitution of comets are also very interesting. He held that comets shine by reflected sunlight, a fact that also explained why comets were usually observed near the sun. Newton reviewed the historical ideas concerning comet tails and concluded that they arose from the atmospheres of the comets. He felt that this would not be difficult because "a very small amount of vapor may be sufficient to explain all the phenomena of the tails of comets" (Newton, 1686:606). Newton also suggested that a nova could be produced by the infall of combustible cometary material onto a star.

Newton's views on the orbits of comets were not immediately accepted by everyone. All reasonable doubt would be dispelled by future observations of the comet of 1682. Halley (Figure 1.5) found the orbits of about two dozen comets for which there were sufficient observations and published a catalogue of their elements in 1705. The orbital elements (Chapter 3) for the comet of 1682 showed close correspondence with the comets of 1607 (observed by Kepler and Longomontanus) and the comet of 1531 (observed by Apian). Halley also knew that the great comet observed in the summer of 1456 traveled in a retrograde direction. Although the periods involved in these identifications showed variations (roughly from 75 to 76 years), Halley concluded that all the observations referred to the same comet and wrote: "I may, therefore, with confidence, predict its return in the year 1758. If this prediction is fulfilled, there is no reason to doubt that the other comets will return" (Armitage, 1966:166). He also wrote that if he were correct, "candid posterity will not refuse to acknowledge that this was first discovered by an Englishman" (Armitage, 1966:166).

Halley knew that the planets Jupiter and Saturn would disturb the orbit of his comet. This was expected from Newton's law of gravitation and was the physical reason for the differences in the revolution period. However, detailed perturbation calculations were not made in England but in France, by the astronomer A. Clairaut (1713–65). The job was herculean because all computing had to be done by hand. Clairaut and